ENERGY SAVING

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MELTING CHAMBER WITH A PERFORATED LAYER OF MATERIAL

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The development of an energy-saving melting chamber with a perforated layer of material is discussed. The chamber is capable of ensuring deep integrated regeneration of heat waste and high environmental adequacy of the process.

The problem of energy saving, which is topical for all industrial sectors, is especially urgent for melting processes and plants, including glass-melting furnaces. This is due to the substantial consumption of fuel and energy resources in such furnaces and a significant energy-saving potential, i.e., a significant difference between the actual fuel rate and its theoretical minimum. To solve this problem, several energy-saving technologies are currently being developed, of which the most significant are the following [1]:

– regenerative heating of initial materials;

– thermochemical regeneration of waste gas heat based on the vapor conversion of natural gas;

– transition to a oxygen-fuel energy source;

– use of upgraded air-heaters, such as ceramic recuperators;

– use of regenerative burners;

– implementation of new technologies of fuel combustion.

Technical solutions related to designs of initial material heaters are regarded as the most promising for the nearest future. The schemes of glass-melting furnaces with such heaters are described in [2].

The purpose of the majority of the specified technologies is deep regeneration of the particular kind of heat waste, i.e., the heat flow of the waste gases Q_{wg}. Apart from this waste, a significant share in the thermal balance of melting (including glass-melting) furnaces corresponds to another type of waste, that is, the heat flow via the furnace enclosure into the ambient medium (Q_{am}). Therefore, it is interesting to develop technical solutions ensuring a deep integrated regeneration of both flows Q_{wg}, Q_{am}, and other kinds of heat waste, as well as regeneration of solid, liquid, and vapor-like entrainment. An example of such technical solution is the thermotechnical principle of a melting process based on a perforated layer of material, which has been developed at the Moscow Power Institute (USSR Inventor's Certif. Nos. 1047847, 1058901, 1161502, 1167155, 1222635, 1276627, and 1486482; RF patent No. 2240987 [3 – 10]. This principle is implemented in a melting chamber with a perforated layer of material (MCPL).

The scheme of the MCPL and the variants of the batch layer perforation are shown in Fig. 1.

The main principles of heating and melting a perforated layer are as follows. The briquetted material (glass batch, phosphorite, concentrated apatite, etc.) that fills the melting chamber is a perforated checker including partitions between channels for gas passage and a peripheral shell that serves as a carrier lining and a vertical constantly renewable (as a consequence of melting) enclosure of the high-temperature thermotechnical plant. Combustion components are burned in the gas header and removed through the checker heating it to the melting temperature and thus becoming cooled. An axial channel may exist in the briquette checker for feeding the combustion components. The partitions of the briquette-shaped checker are thermally less solid that the peripheral shell, which ensures their faster heating and melting and the formation of the gas header. The thermal treatment of the shell occurs mainly in the gas header, and its melting proceeds to such a thickness that it get deformed under the weight of the briquette, which ensures a continuous movement of the material layer in the chamber. The emerging melt and the deformed solid phase of the shell arrive at the melting tank, where the melting process and the overheat of the melt are completed.

The described process of heat-treating material in a perforated layer is experimentally confirmed on the "warm" and fire-test beds using as initial materials paraffin, alumino-

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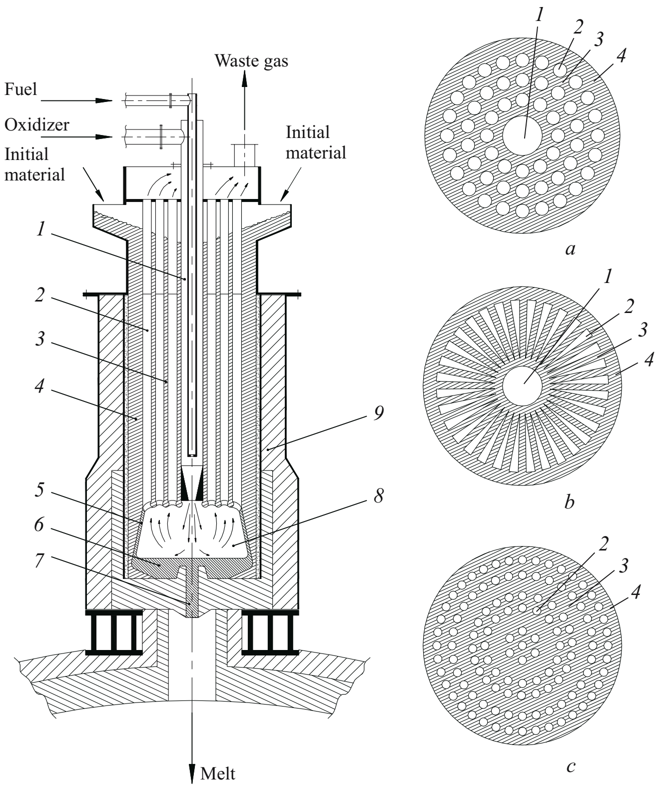

Fig. 1. Scheme of MCPL and variants (*a* – *c*) of cross-sections of perforated batch layer: *1*) axial channel; *2*) gas channel; *3*) partitions comprising the checker; *4*) peripheral shell; *5*) melt film; *6*) melting tank; *7*) taphole; *8*) gas header; *9*) enclosure.

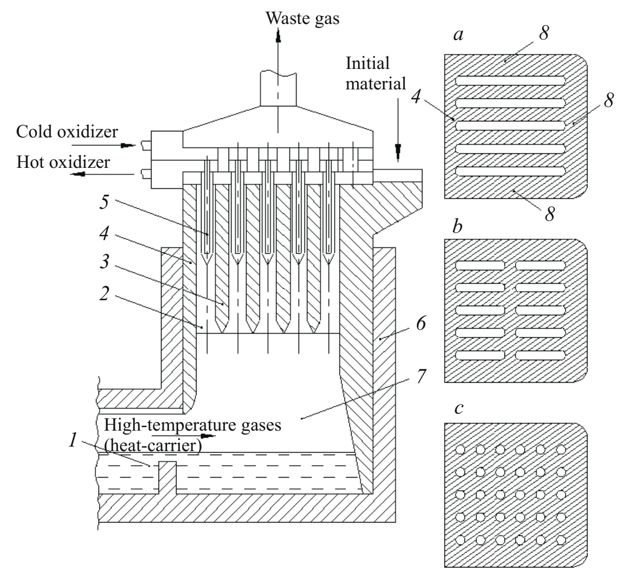

Fig. 2. Scheme of MCPL and variants (*a* – *c*) of cross-sections of perforated batch layer in the shaft antechamber: *1*) tank for additional treatment of the melt; *2*) gas channel; *3*) partitions comprising the checker; *4*) front wall of peripheral shell; *5*) oxidizer heater; *6*) enclosure; *7*) gas header; *8*) back and lateral walls of peripheral shell.

borosilicate and soda glass batches, phosphorite, and concentrated apatite. It has been observed that the briquette melting rate, the temperature field, and the header size in the established conditions are constant.

The resultant heat-flux density in the header makes a substantial contribution to the stability of the process. This is especially topical for multicomponent glass batches that have a wide temperature interval between their softening temperature and the fluid state and a high yield of volatile components at the melting temperature. This facilitates the formation of a swelled viscous layer on the checker surface in the header. At the same time, the heat-flux density of 30 – 40 kW/m^2, which is easy to achieve in flame furnaces, guarantees a relatively small width of the viscous layer and thus prevents “sticking” in the channels and ensured free passage of flue gases.

The melt formed on the header walls, depending on the partition shape (Fig. 2), either descends in the form of drops, or in the form of film flows into the melt tank and then is removed from the chamber via the tap-hole. The displaced nonmelted shell layer keeps moving along the tank enclosure and becomes melted near the tap-hole. Thus, not only the vertical shaft walls, but the majority of the tank enclosures, are protected from aggressive and high-temperature products by the nonmelted material. The level of overheating of the melt in the chamber primarily depends on the heat-flux density in the header, the time that the material stays in the header, and the location of the burners and may achieve significant levels.

By varying the shell thickness and the briquette weight, it is possible to significantly decrease the heat-flux density from the external surface of the briquette to the ambient medium, due to its regeneration with the material of the peripheral briquette shell.

The study of temperature fields in the peripheral briquette shell, which provides the regeneration of the heat flow directed to the ambient medium, indicates that the temperature of the outer surface of the briquette up to 3/4 height of the MCPL height, counting from the cold end, is more than 100°C. Even in small-scale plants with a relatively low thermal resistivity of enclosures (up to 0.62 m^2 · K/W) consisting of a metal casing and material filling, the heat loss to the ambient medium is not higher than 1% [6]; furthermore, the aggressive high-temperature process products do not directly contact the chamber walls.

In the MCPL chamber variant in Fig. 2, the melting chamber is additionally equipped with a heater for the oxidizer *5*.

The high-temperature gases, constituting a mixture of combustion products and batch gases, move from header *7* upwards along channels *2*, heating the checker up to the melting temperature and becoming deeply cooled in doing so.

In the chamber variant shown in Fig. 1, high-temperature gases are formed in combustion of the components in header *8*. An axial channel *1* can be provided in the perforated layer to feed the combustion components into the header. In this

case it is possible to obtain an impact flame with respect to the melt tank surface *6*, which significantly intensifies the external heat exchange between the combustion products and the melted material.

In the MCPL variant in Fig. 2 the feed of high-temperature gases (acting as fuel) to header *7* is carried out from the working space of tank *1* for additional treatment of the melt. To provide a lateral feed of gases to the MCPL, the front wall *4* of the peripheral shell, which is adjacent to the entrance section of the gas flow, is thinner than the other walls *8* (lateral and back walls) of the shell. This ensures the accelerated melting of the front wall and the access of gases into the MCPL.

The chamber along its height can be subdivided into two zones: heating and melting zones (Fig. 3). The material retains its initial geometry within the heating zone, whereas in the melting zone only its peripheral shell is preserved. As a result, it is possible to ensure a rational combination of external heat transfer variants: radiation transfer in the melting zone, radiation-convection in the lower part of the heating zone, and convection in the upper part of the heating zone.

The MCPL has the following design and technological peculiarities:

– a counterflow scheme of the heat carrier and the material, an extended heat transfer surface in the heating zone;

– a rational combination of heat transfer by radiation and by convection;

– independence of thermotechnical parameters of the heating zone on the amount of entrainment in relation to the heat exchange surface, due to the continuous renewal of this surface;

– protection of the chamber enclosure from aggressive and high-temperature products by a constantly renewable shell of unmelted material.

The considered chamber is capable of a deep integrated regeneration of two types of heat waste: Q_{wg} and Q_{am}. The regenerating heat-carrier is the initial material (batch, etc.). As a consequence, the fuel rate can be brought closer to its theoretical minimum.

Due to the substantial decrease in the temperature of waste gases, the MCPL makes it possible to collect and regenerate the vapor-like entrainment of material in the heating zone. Consequently, the extended surface of the heating zone of the perforated layer and the low temperature of waste gases ensure a substantial saving of material resources. The advantage of the MCPL is its extended campaign duration together with savings in the costs of refractories and heat insulation.

Thus, it is possible to obtain economies by cutting on capital cost, fuel, and material consumption. Furthermore, the decreased fuel rate accompanied by a decreased quantity of waste gases and the regeneration of entrainment of material components ensure a high ecological efficiency of the melting chamber.

In the context of the above-mentioned energy-saving technologies, glass-melting furnaces are now commonly converted to an fuel-oxygen (oxy-fuel) energy source. Since 1990, more than 200 glass-melting furnaces in the world have been converted from air-fuel to oxy-fuel heating [11]. In Northern America 25% glass-melters have undergone this transition [12]. In this case the volumetric flow rate of waste gases has decreased by 20 – 33%, which saves fuel and decreases electricity consumption on forced-draft equipment.

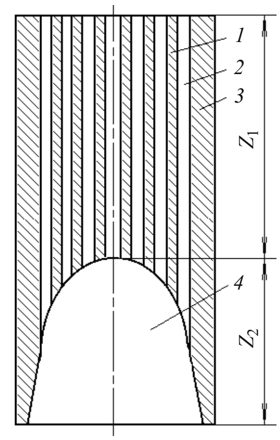

Fig. 3. Zones of the melting chamber with a perforated layer: *1*) partition; *2*) gas channel; *3*) peripheral shell; *4*) gas header; Z_1) heating zone; Z_2) melting zone.

In some case this transition to oxy-fuel heating has been accompanied by an increasing rate of corrosion of the refractory roof and increased vapor entrainment of alkali batch components [11]. These problems can be successfully solved in a MCPL, since high-temperature gases have no contact with refractories and the extended heat-exchange surface in the heating zone contributes to trapping entrained particles.

The project of a submerged combustion melter (SCM) equipped with oxy-gas burners has been developed since 2003 [13]. The participants of this project are companies producing about 50% glass in the USA. Compared to the SCM, the chamber with the perforated layer has fewer reasons for an increased entrainment of easily volatile batch components and fewer problems with melt clarification. It is possible to combine the principle of the perforated layer with the submerged combustion principle that develops a boiling melt layer.

The possibility of an efficient implementation of the perforated layer principle has been tested at the fire-testing bed at the Moscow Power Institute, taking aluminoborosilicate and soda glass batches, phosphorites, and concentrated apatite as initial materials.

Figure 4 shows the melting zone of the MCPL obtained in the course of the experiment, which operated on rectangular glass batch briquettes (Fig. 2*a*). The experiments corroborated the main concepts of heat and mass transfer in the perforated layer, its technical feasibility, and thermotechnical and environmental efficiency:

– the thermal balance (consumption) at the fire testing bed gives Q_{wg} and Q_{am} equal to 10.8 and 0.4%, respectively;

Fig. 4. Melting zone of MCPL (experiment on a fire test bed).

– in some experiments we observed settlement of dust-like entrainment in the low-temperature part of the heating zone of the MCPL.

The study of the mathematical model of the MCPL suggests the following [6]:

– the optimal weight part of the checker in the heating zone of the chamber is 0.70 – 0.85 of the total weight of the briquette;

– the actual attainable level of waste gas temperature is 150 – 100°C or below;

– the preferable duration of the chamber operation is 8 – 35 tons/day; to ensure a longer performance, one should use the module principle implying a parallel installation of a required number of melting chambers.

A characteristic feature of the melting zone of the MCPL is the fact that, due to the motion of the material, the heat-flux densities to the inner surface of the peripheral shell $q^{\mathrm{i}}_{\mathrm{am}}$ and on the outer surface of the enclosure $q^{\mathrm{e}}_{\mathrm{am}}$ differ by more than an order of magnitude. Analysis of the thermal performance of the melting zone [14] based on a 2D model of the motion of a melting material shows that

$$q^{\mathrm{i}}_{\mathrm{am}}/q^{\mathrm{e}}_{\mathrm{am}} \le 0.02.$$

This points to the high efficiency of material regenerating the heat waste directed via the enclosure to the ambient medium.

The calculation and analysis results agree with experimental data and corroborate the vast potential of the MCPL as a plant with a deep complex regeneration of heat waste of the melting process and a high level of thermotechnical and environmental adequacy.

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